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(71) Applicant(s)
John Karl Atkinson
Willow House, Wellow Wood Road,
SHERFIELD ENGLISH, Hampshire, SO51 6EP,
United Kingdom

Andrew William James Cranny
103 Harbourne Gardens, West End, SOUTHAMPTON,
SO18 3LZ, United Kingdom

Russell Paul Sion
Flat 6 Arnold House, Arnold Road, SOUTHAMPTON,
SO17 1TG, United Kingdom

(72) Inventor(s)
John Karl Atkinson
Andrew William James Cranny
Russell Paul Sion

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U1S S1770

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(74) Agent and/or Address for Service
John Karl Atkinson
Willow House, Wellow Wood Road,
SHERFIELD ENGLISH, Hampshire, SO51 6EP,
United Kingdom

(54) **A force sensitive device**

(57) A force sensor comprises an insulating or insulated substrate which is in the form of a washer and carries one or more strain sensing resistors fabricated as thick film devices, e.g. using a commercially available thick film resistor paste. When a force is applied, the resistance of the resistor(s) will change due to the changes in geometry experienced, in addition to any piezoresistive effects on the resistivity of the resistor material. The device described uses three or four resistors each fabricated by depositing an orthogonal pair of conductive strips with a layer of resistor paste sandwiched therebetween. The resistors thus have very small surface areas onto which the applied force can be concentrated, increasing the strain experienced by the resistors for any given modulus of elasticity. The device is stated to be cheaper to construct and potentially more robust than the more traditional resistive strain gauges, and to have a higher than usual strain sensitivity.

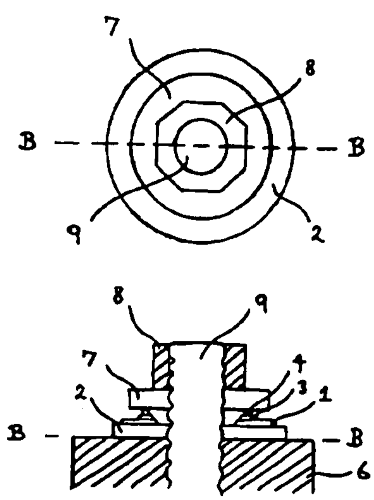

FIGURE 4

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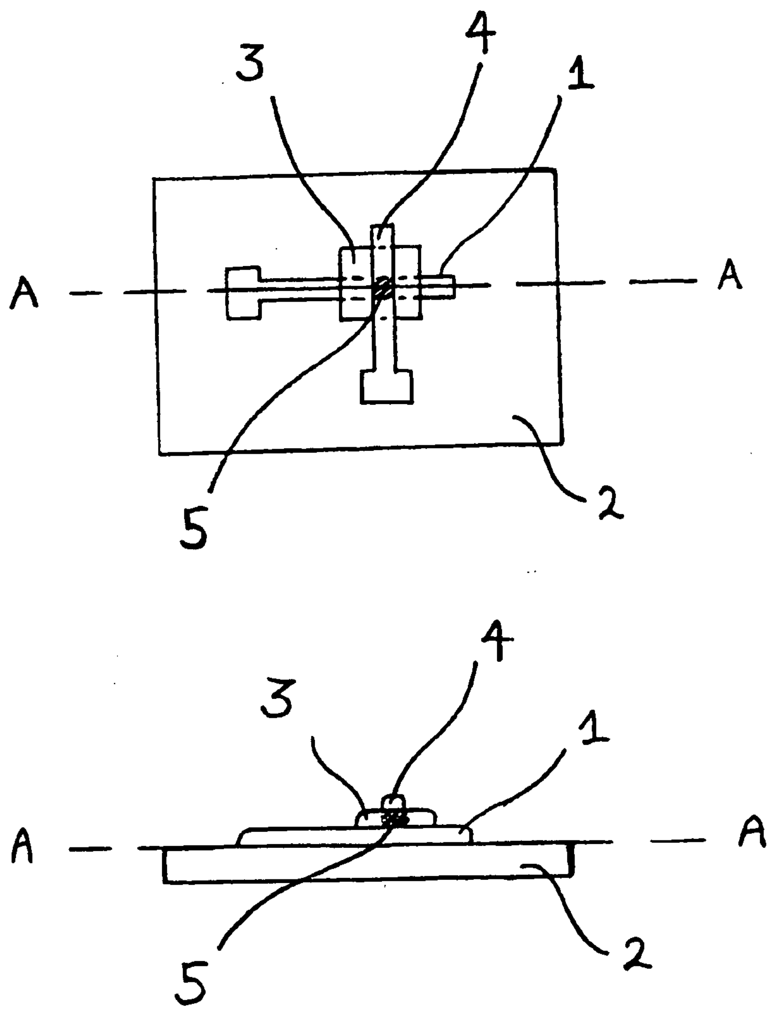


FIGURE 1

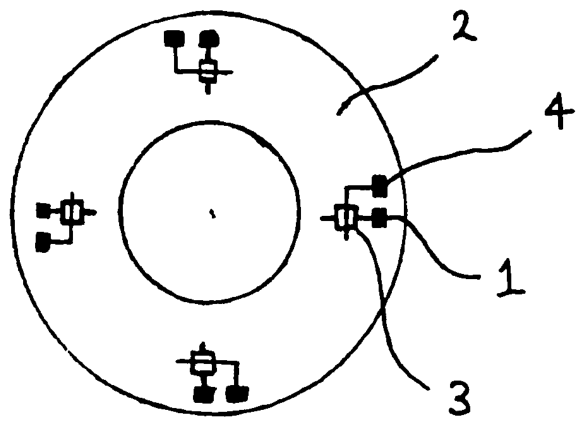


FIGURE 2

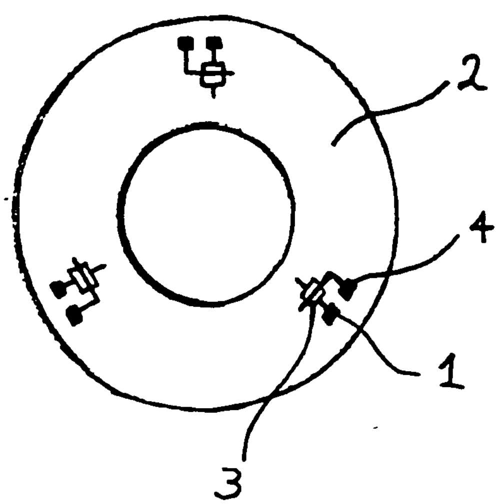
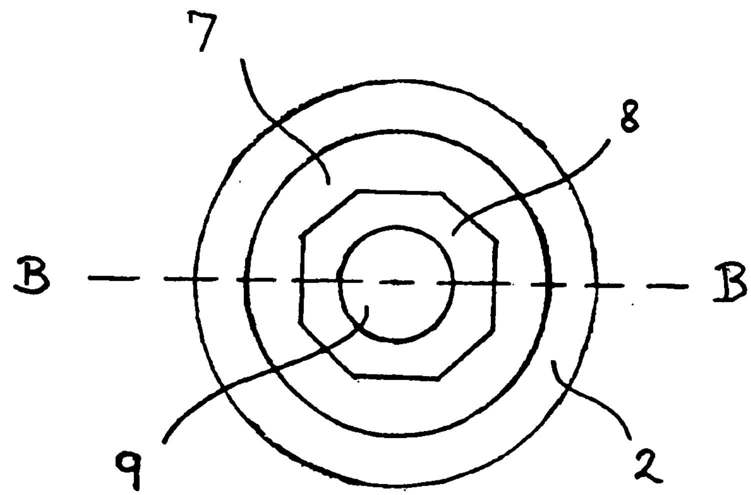


FIGURE 3



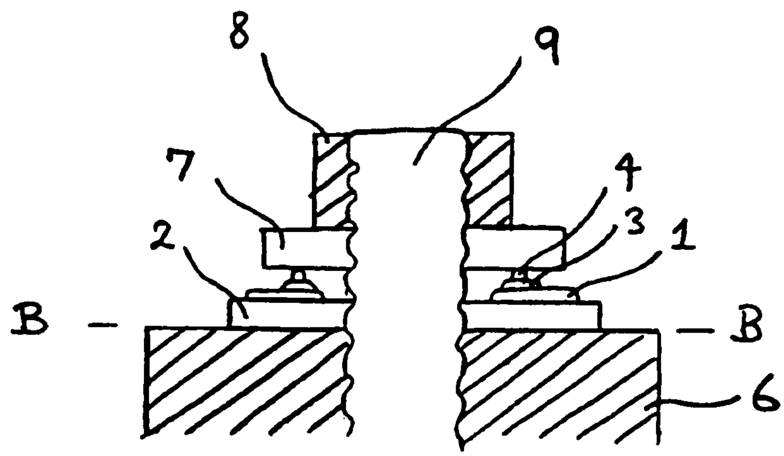


FIGURE 4

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A force sensitive device

Introduction

This patent describes an invention which enables the force experienced by a simple sensor to be converted into an electrical signal which is then capable of being used as a measure of the degree of force experienced by an object to which the sensor is attached. For example the invention may be used to realise a force sensitive washer which can be mounted between a retaining nut and an internal combustion engine cylinder head block in such a manner as to enable the pressure pulses caused by the engine to be measured.

Background of the Invention

The electrical measurement of force is particularly useful in certain application areas where for example it is desirable to instigate some degree of control over a process or operation which produces the force. One such example is the internal combustion engine where the measurement of the force experienced at certain strategic locations on the engine block or cylinder head, for example, can be used to determine the pressures exerted by the engine's firing or combustion cycle. The exact timing of the point of maximum pressure is particularly useful information which can be gainfully employed in an engine management system such as might be realised by a controlling microcomputer. Hence a continuous electrical signal which is proportional to the engine pressures at all times is of particular use since this signal enables the precise timings of the various levels of engine pressure to be accurately measured.

Another attractive option in the control of internal combustion engines is the ability to control air/fuel mixture ratios to the point of extreme settings in order to obtain optimum performance. Very often this strategy results in unwanted side effects such as the occurrence of engine-knock. A sensor capable of measuring engine pressures can be used in this context to enable the early detection of the onset of engine-knock and hence facilitate the so-called "lean burn" mode of operation of the engine which is popular among engine manufacturers.

There is a considerable amount of prior art in the area of the electrical measurement of force, particularly with regard to load sensing. Much of the prior art is public domain and methods for measuring force utilising piezoelectric materials such as quartz or lead zirconium titanate are well established. Another popular technique for measuring force is by utilising the piezoresistive effect exhibited by most materials and the use of electrical resistance strain gauges in this context is very well known.

Of the piezoelectric devices, most of the devices employed in the prior art are inherently expensive due to the need for complex manufacture to render them suitable for mechanical mounting. In addition the associated electrical circuits needed to measure their output signal, which takes the form of released charge, are also complex and expensive. Further disadvantages to the use of piezoelectric devices are their poor response at low frequencies and their high susceptibility to the unwanted effects of temperature variations.

Piezoresistive devices generally use comparatively inexpensive electrical circuits to measure the changes in resistance which result from the strain experienced due to applied force. A major problem in many applications however is the difficulty in mounting resistive strain gauges in a suitable mechanical arrangement. This latter consideration stems from the fact that it is often not possible to locate a resistive strain gauge at a point where it will experience sufficient strain to enable an accurate measurement to be made. Also the use of adhesives in the mounting of resistive strain gauges makes them particularly susceptible to the problem of creep between the gauge and the supporting structure. Metal foil resistive strain gauges, which are the most popular, also suffer from a low sensitivity

The present invention overcomes most of the difficulties referred to above by making it possible to fabricate a device in such a way that relatively high levels of strain can be experienced by the piezoresistive material comprising the force sensor. Additionally the invention described here is inherently cheaper to construct and potentially more robust than the more traditional resistive strain gauges. The device is also less prone to the problems of creep and temperature fluctuation, whilst offering a higher sensitivity to strain and a good response at low frequencies.

Summary of the Invention

According to the present invention a piezoresistive material is deposited onto a substrate in such a manner as to form an electrical resistor. The orientation of current flow in the resistor may be in one of several planes relative to the applied force which is to be measured.

When the resistor is subjected to an applied force, its resistance will change due to the changes in geometry experienced, in addition to any piezoresistive effects on the resistivity of the material comprising the resistor.

The relationship between the applied strain (ε) and the change in resistance (δR) of an electrical resistor of resistance R ohms, when the strain is applied in the same plane as the electrical current flow through the resistor, is given by the following equation:

$$\delta R/R = \varepsilon\,(1 + 2\nu) + \delta\rho/\rho \qquad \{\text{Equation 1}\}$$

where ν is Poisson's ratio for the material comprising the planar electrical resistor and ρ is the electrical resistivity of the material. The term $\delta\rho/\rho$ is often referred to as the piezoresistive coefficient of the material comprising the resistor.

In the present invention a preferred embodiment of the sensor is where the material comprising the electrical resistor is a commercially available thick film resistor paste. This confers several advantages including a strain sensitivity higher than that of most commercially available resistive strain gauges due to a higher value for the $\delta\rho/\rho$ term shown in Equation 1. Additionally it is possible to fabricate the sensor in such a way as to produce very small surface areas for the electrical resistors onto which the applied force can then be concentrated. This in turn concentrates the stress due to the applied force, and consequently the strain experienced by the strain sensing resistor for any given modulus of elasticity.

A preferred embodiment of the invention is also one where the force applied and the electrical current flow through the strain sensing resistor are both normal to the plane of the supporting substrate. This mode of operation results in an optimum level of sensitivity due to the fact that the piezoresistive coefficient is maximised whilst the effect of any temperature coefficient of expansion mismatch between the substrate and the materials comprising the strain sensing resistor is minimised.

Figure 1 shows a typical embodiment of the strain sensing resistor where a highly conducting layer of material *1* is deposited onto a suitable insulating substrate *2*. A resistive material *3* is then deposited on top of the bottom layer conductor *1* and a further layer of high conductivity material *4* is deposited on top of the resistive material *3*. The conducting layers *1* and *4* may be deposits of a suitably processed commercially available thick film paste containing a suitable conductive material such as gold although other materials may be used. A suitable supporting insulating substrate *2* may be made of aluminium oxide although other materials may also be used. The resistive layer *3* may be a suitably processed commercially available thick film resistor paste or other suitably strain sensitive material.

The cross-section along the line AA in Figure 1 shows the overlapping nature of the layers which are arranged so as to leave a small area of resistive material sandwiched between the two conducting layers. This area of overlap *5* (shown hatched in figure 1) is designed to be as small as is practical for the particular application for which it is intended. This is in order to maximise the amount of stress, and hence strain, experienced by the resistor for any given applied force.

One example of a simple force sensor which utilises the strain sensing resistors shown in figure 1, is illustrated in figure 2. This embodiment of the invention shows an arrangement of four strain sensitive resistors, each being such as that shown in figure 1, placed equidistantly around a circular washer *2* which may be made of an electrically insulating material such as aluminium oxide, or some other suitable material. The exact number of strain sensing resistors employed in this embodiment is arbitrary and other numbers may be utilised, including the case of a single strain sensing resistor. Electrical connection to the strain sensing resistors can be made by the attachment

of wires, by soldering or other suitable method, to the conducting layers *1* and *4* of each of the resistors.

There is however some merit in placing three strain sensing resistors equidistantly around the circumference of a washer, such as shown in figure 3, in that approximately equal strains are experienced in the resistors due to the equal distribution of any applied force when the washer is subsequently mounted. This results from the principle of a tripod which is always able to balance even on a less than flat surface.

Figure 4 shows a plan view, and a cross-section along the line BB, of a typical mounting arrangement for the embodiment of the force sensor here described. An electrically insulating washer serves as a supporting substrate for the strain sensing resistors comprised of the conducting layers *1* and *4* and the sandwiched resistive layer *3*. The washer is mounted over a securing stud *9* which is screwed into an engine block *6* . An electrically insulating top washer *7* is secured in contact with the strain sensing resistors by a retaining nut *8*.

With the arrangement here described, any forces experienced by the retaining nut, due to pressure pulses in the engine block for example, will result in a strain being experienced by the strain sensing resistors mounted on the washer. This strain will result in a change in the resistance of the resistor which can then be measured using a suitable electrical circuit such as a Wheatstone's bridge for example.

A preferred embodiment of the invention is where the equidistantly arranged strain sensitive resistors, such as the arrangements illustrated in figures 2 and 3 amongst others, are electrically connected in series. Such an arrangement is then significantly less sensitive to strains induced into the strain sensitive resistors arising from pressure components that are not parallel to the mounting stud *9* and orthogonal to the force sensing washer *2*. In this embodiment changes in the combined resistance of the strain sensing resistors will indicate the total strain that is experienced by the resistors regardless of how it is distributed between the individual devices. Thus if there were any tendency for the stud and washer assembly to rock sideways the component of strain so produced

would be cancelled out by this mounting and electrical interconnection arrangement of the strain sensitive devices.

Claims

1. A device for sensing force which utilises strain sensing resistors fabricated as thick film resistors on an electrically insulated substrate material which by its construction may be used to form a force sensing washer.

2. A device as described in claim 1 above where the insulating substrate consists of a metal washer with a deposited electrically insulating layer onto which the force sensing resistors can be subsequently deposited.

3. A device as described in claim 1 where the force sensing resistor is formed by a resistive material sandwiched between the overlap of two conducting layers.

4. A device as described in claim 1 where the applied force is orthogonal to the supporting substrate and the strain sensing resistors are fabricated as planar resistors.

5. A device as described in claim 1 where the applied force is both parallel to the electrical measurement current flowing in the strain sensitive resistors and orthogonal to the supporting substrate.

6. An arrangement of equidistantly spaced strain sensitive resistors in a device as claimed in claim 1 which are electrically connected in series for the purpose of measuring their change of resistance.

7. A method of individually measuring equidistantly spaced strain sensitive resistors in a device as claimed in claim 1 and then summing or averaging their values to determine their average level of experienced strain.

Amendments to the claims have been filed as follows

1. A device for sensing force which utilises strain sensing resistors fabricated as thick film resistors printed onto the surface of an electrically insulating substrate which by its construction may be used as a force sensing washer whereby the strain sensing resistors can be subjected to force which produces a measurable change in their electrical resistance.

2. A device as described in claim 1 where the electrically insulating substrate consists of a metal washer with a deposited electrically insulating layer onto which the force sensing resistors can be subsequently printed.

3. A device as claimed in claim 1 where the strain sensing resistors are formed from a resistive material sandwiched between the overlap of two layers of conducting material such that the direction of sensed force is orthogonal to the supporting substrate and parallel to the electrical measurement current flowing in the strain sensitive resistors.

4. A device as claimed in claim 1 where the strain sensing resistors are fabricated as planar resistors and the direction of the sensed force is orthogonal to the supporting substrate and the electrical measurement current flowing in the strain sensitive resistors.

5. A device as claimed in claim 1 with an arrangement of roughly equidistantly spaced strain sensitive resistors which are electrically connected in series for the purpose of measuring their change of resistance or have their change in resistance individually measured and then summed in order to determine the total level of applied force.

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Application No: GB 9603387.3
Claims searched: 1-7

Examiner: M. G. Clarke
Date of search: 21 April 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N NAFD8, NAGB8; G1W

Int Cl (Ed.6): G01L 5/24; F16B 31/02

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB2187887A	Marelli Autronica SpA - whole document	1 at least
A	GB2184239A	Marelli Autronica SpA - whole document	
X	EP0140066A1	Robert Bosch GmbH - whole document	
A	US5222399	assigned to Fel-Pro Inc - whole document	
A	US4106370	R.A.Kraus et al. - whole document	

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